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Experimental investigation of the impact of shape-stabilized phase change material integration on the thermal performance of brick walls in buildings

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Abstract

The increase in the amount of energy consumed to meet the specific needs of users in buildings has accelerated the research on the enhancement of building materials with high thermal energy storage capacity in recent years. In the present study, the effect of using a new shape-stabilized phase change material (SSPCM) instead of conventional hollow bricks in the building envelope was investigated. SSPCM was prepared by combining methyl palmitate (MP) used as phase change material (PCM) and expanded vermiculite (EV) as support material. In order to obtain optimum thermal performance, filling of SSPCM into hollow bricks constituting the outer envelope of buildings was evaluated by considering different configurations regarding amount and location. While lower indoor temperatures were provided in the test room during the daytime when maximum temperatures were observed with SSPCM-filled bricks, higher indoor temperatures were achieved at night regarding the maintenance of temperatures. By applying the proposed composite (EV/MP), a cooler indoor environment was created with a maximum difference of 7.05 °C compared to the reference during the hours when solar radiation intensity increases the ambient temperature. At night, when ambient temperatures dropped, a maximum advantage of 2.16 °C in indoor temperature was determined. The study findings show that the use of EV/MP integrated bricks in building applications plays an important role in reducing heating/cooling loads by contributing to the realization of temperature control.

Keywords: Energy storage and saving, Renewable energy, Shape-stabilized PCM, Thermal comfort, Thermal performance analysis

1. Introduction

Global energy consumption is constantly increasing due to the rapid increase in population, the demand for high living standards accompanied by industrialization and technological progress. Fossil fuels, which are greatly used to meet this requirement, cause environmental problems such as greenhouse effect and global warming. The increase in energy prices, limited reserves of primary resources, environmental problems such as greenhouse gas and global warming have accelerated the research on the use of alternative energy sources. Solar energy is one of the most environmentally friendly renewable energy sources that is highly effective in reducing fossil fuel dependency. Its various advantages such as clean, abundant and ease of accessibility, have made it one of the most promising among these resources (Wu et al., 2020). However, the lack of full accessibility to solar energy causes problems in continuity of use (Şen, 2004; Ohunakin et al., 2014). Thermal energy storage systems (TES), which emerged as a solution to the mentioned disadvantage, stand out as technologies that allow energy to be stored when it is abundant and cheap to be used later at the desired time and place (Cabeza et al., 2015; Gasia et al., 2017; Sarbu & Sebarchievici, 2018). Latent heat storage (LHS) systems, which can be used in processes where a constant temperature heat is required, offer advantages such as high storage densities for small temperature ranges and being able to work in an integrated manner with active and passive systems when compared to other TES systems (Mavrigiannaki & Ampatzi, 2016; Zhang et al., 2018; Jouhara et al., 2020). Since smaller storage volume is required with LHS, similar amount of energy can be stored with less material applied. In this way, it contributes to the reduction of costs in storage or energy conversion processes. Thus, a contribution is made regarding the reduction of costs in energy conversion and storage processes (Zhang et al., 2016; Zeinelabdein et al., 2018; Alemam et al., 2024; Liu et al., 2024).

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In the building sector, which has a significant share in global energy consumption, LHS systems have become a subject that attracts the attention of researchers in minimizing energy consumption in meeting thermal comfort needs (Mavrigiannaki & Ampatzi, 2016; Ray et al., 2021). "Phase change materials" (PCMs) encountered in LHS applications are defined as materials that can store/release thermal energy via their latent heat during the phase change they undergo for a certain temperature range (Zeinelabdein et al., 2018; Carnie et al., 2024). The storage and release of heat occurs through endothermic and exothermic processes within the phase change (Javadi et al., 2020). The decrease in thermal mass due to the preference of lightweight materials instead of giant structures due to the developments in the construction sector leads to irregularities in indoor air temperature and increases in heating/cooling loads (Marin et al., 2016; Bamonte et al., 2017). The inclusion of PCMs in building applications can play an important role in improving thermal mass and contribute to minimizing energy losses (Soares et al., 2017; Yadav et al., 2024a). The use of PCMs in buildings can be realized in two different ways: passive or active (Beyhan et al., 2017). In passive applications (PTSS) where natural convection is effective without the need for an auxiliary equipment in the system, PCM is imposed on building elements such as gypsum, concrete, walls, floors, windows or roofs (Sadineni et al., 2011; Soares et al., 2013; Gholamibozanjani & Farid, 2021). Integrating PCM into building components is effective in facilitating temperature control, increasing durability, reducing energy consumption and delaying the loading of thermal peaks (Soares et al., 2013; Stritih et al., 2018; Jiao et al., 2024).

In order to fully demonstrate the contributions of PCM in terms of energy efficiency in the building sector, it is important that it is sustainable in practice. In this context, PCMs should have various physicochemical, kinetic, thermal and economically suitable properties according to their application areas. There is no single perfect PCM that provides all of these features (Alehosseini & Jafari, 2020). Accordingly, different applications and techniques are being developed for the sustainability of LHS systems in which PCMs are integrated (Abreha et al., 2020; Zhang et al., 2020; Khademi et al., 2022). Gao et al. (2020) conducted a numerical study to elucidate the potential of using PCM to improve the thermal behavior of hollow bricks. The results showed that with PCM for suitable phase change temperatures, the delay time can reach 8.83-9.83 hours from 3.83 hours and the peak heat flux can be reduced from 45.26 W/m^2 to 19.19-21.4 W/m^2, but the average values cannot be reduced. Zhang et al. (2011) evaluated the thermal response of a PCM-filled brick wall by performing numerical analysis on a thermal conduction model they created. It was determined that PCM provides advantages in terms of thermal insulation and contributes to temperature hysteresis and thermal comfort of the occupants, while its amount is an effective parameter in smoothing the fluctuation in the inner wall surface temperature. Hichem et al. (2013) studied the potential of improving the thermal inertia of building external walls by considering the location and amount of PCMs with different properties for hot and dry climate conditions. It was observed that the improved brick caused a decrease of 3.8 °C in the inner wall temperature and an 82.1% decrease in the heat flow into the interior environment. Fraine et al. (2019) evaluated the potential to use a new phase change humidity control material (PCHCM) instead of expanded polystyrene foam (EPS) for hygrothermal insulation of building construction. PCHCM was determined to have an energy saving potential of up to 50%. It was found that an increase in the PCHCM filling ratio decreased the decrement factor while increasing the time lag for both the inner surface temperature and relative humidity. A study was conducted by Markarian and Fazelpour (2019) to calculate the optimum type and location of PCM to be used in order to reduce heating and cooling loads in residential building located in different climate types in Iran. It has been determined that electricity savings of 4.5-5.5% are achieved with PCM for all climates. Figueiredo et al. (2017) determined the effect of PCM for a building connected to a geothermal system, both in terms of thermal comfort and energy efficiency, through experimental and numerical analyses. In the experimental results, it was found that PCM provides a 7.23% reduction in overheating rate for the summer season, which corresponds to a PCM efficiency of 35.49%.

While integrating PCMs into building elements offers significant advantages, issues such as leakage and the inability to maintain thermal stability during phase change in PCMs pose certain limitations to their application. Shape-stabilized PCMs (SSPCM), in which PCMs are impregnated into porous supporting materials, are emerging as an alternative solution to these problems, enabling more effective use of PCMs in building applications (Gencel et al., 2021; Yaras et al., 2022). Yadav et al. (2024b) evaluated the novel SSPCMs they produced to improve the problems encountered during the application of PCMs in TES systems. Compared to the base PCM, the thermal conductivity of the synthesized SSPCMs increased by 657.16% and reached 1.59 W/mK. The thermoelectric efficiency of the SSPCM composite in converting thermal energy was calculated as 70.89%. de Dios Cruz-Elvira et al. (2022) presented the thermophysical properties of a new form-stable PCM composite (dodecanol/tepexil). The calculated thermal conductivity of the dodecanol/tepexil composite is 0.308 W/mK (for 30 °C), which is two times higher than that of dodecanol. It was also stated that the composite is one of the candidate materials that can be preferred in building systems for the thermal comfort range of 21–26 °C due to its properties. Noël and White (2021) characterized different form-stable PCMs in which the PCM was integrated into a solid, porous matrix. The best result in terms of thermal conductivity was obtained with alumina containing 38% PCM by mass. A significant improvement of up to 3.2 W/mK was observed compared to the 0.15 W/mK calculated for pure PCM. The investigations showed that the hardness and mechanical stability were good even after 1000 cycles.

Recently, within the scope of studies carried out to regulate indoor temperatures by improving the heat storage capacity of the building envelope and to optimize heating-cooling loads; the applicability of bricks in which the shape-stabilized EV/MP composite is included is examined in the present article. Vermiculite, which stands out as a natural, light and heat-resistant mineral, was used as a support material. With expansion, the bulk density of vermiculite decreases significantly and becomes a material with high absorbency and fire resistance. MP was preferred as PCM in terms of its chemical and thermal stability properties. It can be said that EV/MP composite is a functional material for TES applications in terms of increasing thermal comfort in buildings and improving energy efficiency. The study, which focuses on the development of new green building materials with high energy efficiency, provides an important contribution to the literature in terms of examining the conditions that will provide optimum performance of SSPCM composites in bricks. The data obtained on the solar thermal regulation performance of bricks with and without EV/MP for different configurations under actual weather conditions provide a comprehensive view on the control of indoor temperatures in buildings and the improvement of energy savings.

2. Material and methods

2.1. Materials

Expanded vermiculite (EV), which was used as a support material in the experiments in terms of being an environmentally friendly choice with its properties, was supplied from a commercial company in Turkey. Methyl palmitate (MP/CAS: 112–39-0), which was purchased from Merck and has a purity of ≥ 99%, was used as heat storage and thermal regulator PCM material in the preparation of SSPCM composites due to its suitable phase transition temperature and high thermal properties. The melting temperature and corresponding latent heat of MP are 26.74 °C and 244.0 J/g, respectively. The solidification point is 24.75 °C and the solidification enthalpy is 239.0 J/g. Table 1 presents the basic physical properties of EV and the shape-stabilized EV/MP composite. Integration of MP into the structure of EV was carried out by direct mixing technique. A total of three mixtures were produced depending on the mixing ratios. In the preparation of SSPCMs containing EV and MP, in the first stage, melted MP was mixed with EV in certain amounts (40-50% by weight). After the formation of EV/MP mixtures, leakage test was carried out to determine the optimum MP loading ratio for leak-free EV/MP composite. The prepared mixtures were heated on filter papers at a temperature above the melting point of pure MP (60 °C) for one hour. After this process, possible MP leakage in the samples was checked by both visual inspection and mass change calculations for the pressed sample blocks. The preparation process of the shape-stabilized EV/MP composite is given in Figure 1. The test results showed that the highest leak-free MP integrated ratio in the EV/MP composite was 45 wt%. Therefore, the mixture containing 45 wt% MP was defined as shape-stabilized EV/MP composite PCM. The melting and solidification points for EV/MP (45 wt%) are 26.81 °C and 24.83 °C, respectively. The latent heat of melting is 109.2 J/g and the latent heat of solidification is 107.1 J/g.

Table 1. Basic physical properties of EV and shape-stabilized EV/MP composite

Property	EV	EV/MP
Density (kg/m³)	150	238
Porosity (%)	85	55
Thermal conductivity (W/mK)	0.0873	0.0940
Melting temperature (°C)	-	26.81
Latent heat (kJ/kg)	-	Melting : 109.2 Solidification:107.1
Thermal capacity (J/g·K)	0.93	1.735

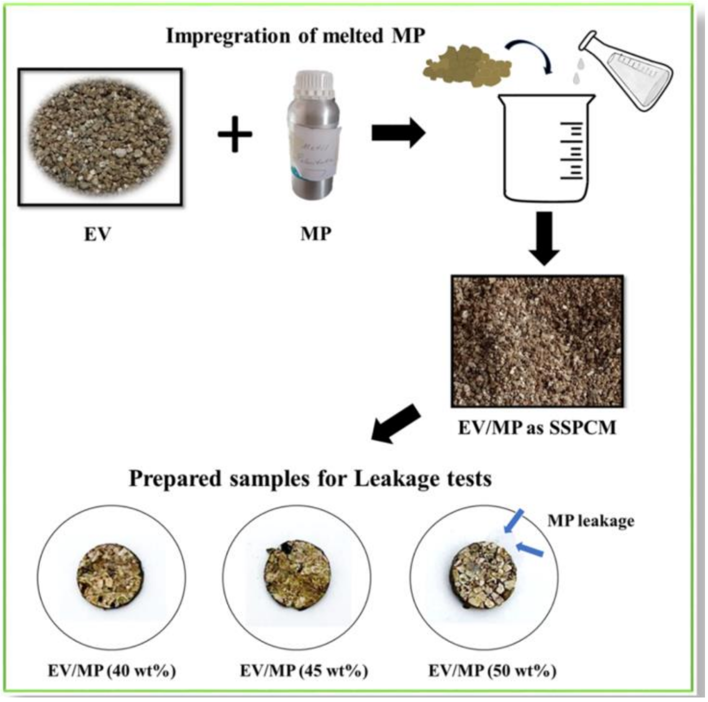

Figure 1. Preparation steps of shape-stabilized EV/MP composite.

2.2. Test conditions for thermoregulation performance analysis

For the outdoor experiments conducted to evaluate the energy performance of brick samples with and without EV/MP, four identical test cabins with internal dimensions of 0.192×0.35×0.192 m^3 and containing thermal measurement components as shown in Figure 2(a)-(c) were used. The preferred medium density fibreboard (MDF) thickness in the construction of the cabins was 0.02 m. The experiment study was conducted on the roof of Bartın University Faculty of Engineering, Architecture and Design building (41◦ 38′ 8.99′′ N, 32◦ 20′ 15′′ E) and on sunny-cloudy days (27-30.09.2024). The fact that the obtained temperature data exhibit similar trends depending on the outdoor environment changes in repetitive thermal cycles shows that the three-day measurement period provides stable and representative results for determining the temperature profile of the system. The location chosen for the experiment reflects the characteristics of the Black Sea climate with hot summers and cool winters. To evaluate the performance of EV/MP for cold and hot weather conditions, thermoregulation analyses were conducted on an autumn day when the ambient and indoor temperatures varied above and below the phase change temperature of the PCM. The average value observed for the ambient temperature was around 18 °C, and temperatures below this value can be defined as cold weather. Expanded polystyrene foam (EPS) insulation with a thickness of 0.05 m was placed on the internal surfaces of the test cabins to minimize possible heat losses. The transmission of solar radiation was provided by a double-glazed window (0.14×0.14×0.02 m^3) placed at the top of the cabins. Brick samples with dimensions of 13.5×19×19 cm^3 were placed in the test cabins to be analyzed experimentally as a representative of the exterior wall. Global solar radiation falling on the horizontal surface was determined with the help of a pyranometer (Eko MS-410). The device has a zero offset error of less than 6 W/m². The pyranometer was positioned close to the test cabins to allow clear observation of the effects related to solar radiation. A Hioki LR8450 data logger with 30 channels (accuracy; ± 0.5 °C for 0-100 °C/ ± 20 µV for -20 mV-20 mV) was preferred for converting analog data related to temperature and solar radiation into digital data and recording them.

The monitoring of the temperatures in the test cabins and the ambient temperature was carried out by means of K-type (NiCr-Ni) thermocouples (TC). The inherent accuracy for thermocouples is ± 1.5 °C. To ensure the reliability of the measurements, all thermocouples used were calibrated before experimental analysis and the repeatability of the measurements was verified with different test cycles. As can be seen from Figure 3, five different measurement points were determined in each test cabin. Two thermocouples were used to measure the surface temperature of the exterior wall (brick) samples, one on the outer surface and one on the inner surface. Temperature changes inside the brick was evaluated with two thermocouples positioned in the outer hollow and inner hollow (Figure 3(a)). The measurements recorded for the outer hollow indicate the part of the brick that interacts with the outdoor environment, while the inner hollow shows the temperature measured near the inner surface of the brick. One thermocouple was used to measure the room center temperature of the test cabins. The ambient temperature was monitored with a single thermocouple placed in a way to prevent the effects of wind and solar radiation. The reference to be used for comparative analyses is labeled as REF, while the test cabins where SSPCM is integrated into the outer two row and the inner two row are denoted as OUT2H and IN2H, respectively. In addition, the test cabin containing the sample with all hollows filled with SSPCM is expressed as FULL4H (Figure 3(b)). For the REF test cabin, TC1, TC2, TC3, TC4 and TC5 thermocouples were used. The temperatures in the OUT2H test cabin were measured with thermocouples TC6, TC7, TC8, TC9 and TC10. The temperatures in the IN2H and FULL4H test cabins are expressed as (TC11, TC12, TC13, TC14, TC15) and (TC16, TC17, TC18, TC19, TC20), respectively. The ambient temperature was observed using TC21. Experimental measurements were carried out every 5 seconds A total uncertainty of approximately ± 0.5–1.0 °C is estimated for the temperature measurements associated with the experimental components.

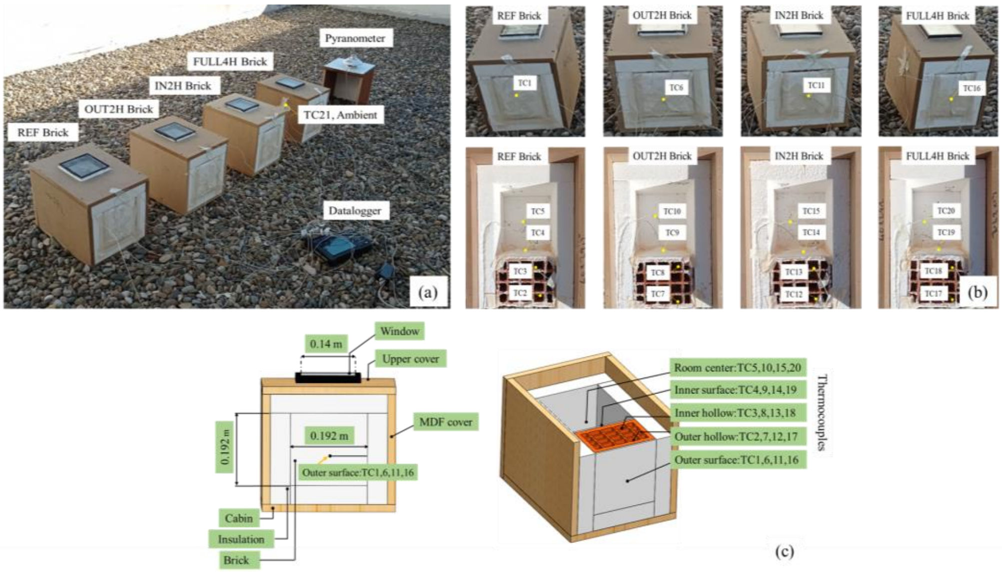

Figure 2. General view of the experimental setup; layout of the experimental setup equipments (a), locations of the thermocouples for test configurations with/without PCM (b), and schematic view of the test room (c).

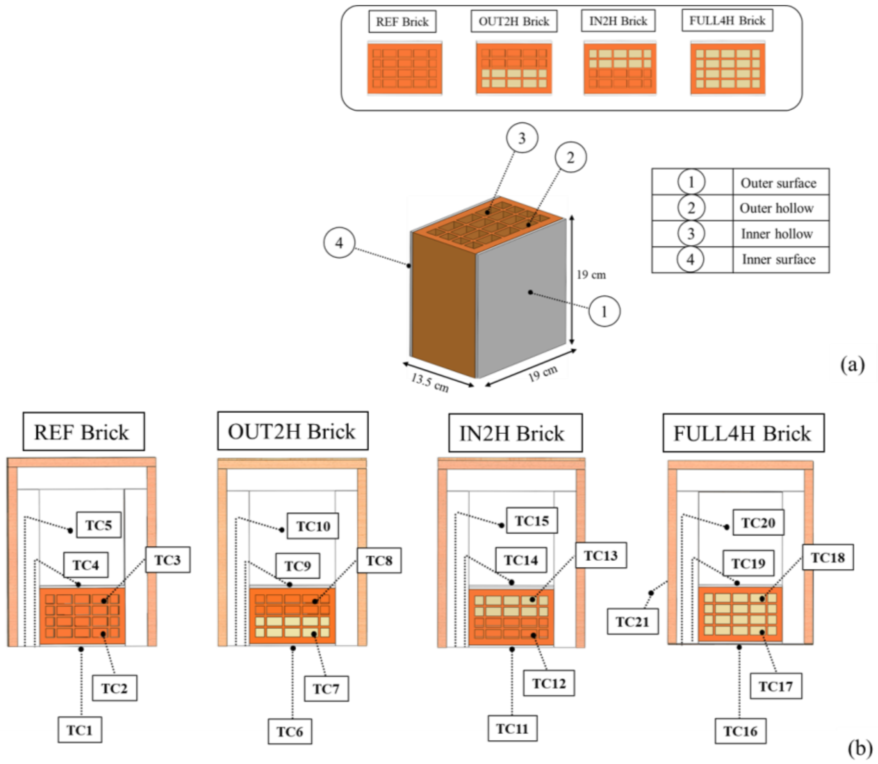

Figure 3. Basic schematic representation of the experimental system; brick structure and investigated configurations (a), and detailed placement of thermocouples at measurement points (b).

3. Results and discussion

In order to evaluate the weather conditions more clearly during the experiment, direct and diffuse radiations are calculated in relation to global solar radiation. Direct solar radiation refers to solar radiation that reaches the ground without any dispersion, reflection or scattering. Diffuse radiation is the part of the incoming solar radiation that reaches the ground by being dispersed under the influence of atmospheric conditions. Global solar radiation on the horizontal surface is composed of the combination of these radiations. These radiations are important in terms of providing information about weather conditions for experimental analyses. The main purpose of the research is to compare the energy performance of bricks containing different amounts of SSPCM with traditional bricks. In the experiments, measuring the ambient temperature and solar radiation together with the cabin temperatures provides a more accurate approach in terms of performance evaluation. In the open-air experiments conducted to examine the performances in actual ambient conditions, temperature changes in the heating and cooling processes were taken into account.

Figure 4 shows the solar radiation data on the horizontal surface obtained by pyranometer on 27-30.09.2024 when a sunny and cloudy sky was observed. The effect of diffuse solar radiation varies depending on the sky clarity index. While direct solar radiation values lower than diffuse solar radiation values define cloudy weather conditions, the opposite situation indicates sunny weather conditions. As can be seen from the solar radiation curves, the data measured during the experiment mostly belong to direct solar radiation. The results confirm the environmental conditions on the day of the experiment. The fluctuations observed in solar radiation correspond to cloudy periods, while the peaks correspond to clear sky periods. The sky on 28.09.2024 was clearer compared to 29.09.2024. Pyranometer measurements were taken on the experimental days from approximately 06:00. The test cabins are in the shade from early morning until this time. Direct solar radiation and the ambient temperature associated with it increase until noon. Maximum values of solar radiation are observed at noon. Maximum values of global and direct solar radiation were observed as 731.41 W/m^2 and 610.88 W/m^2, respectively. The maximum value reached by diffuse radiation is 120.53 W/m^2.The solar radiation then gradually decreased until the test cabins were shadowed at 18:00. This shading that occurs in the afternoon also lowers the ambient temperature.

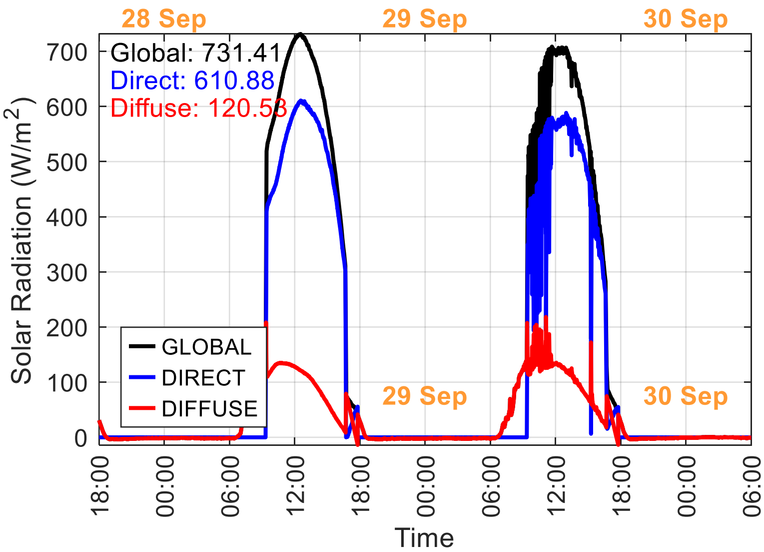

Figure 4. Global, direct and diffuse solar radiation measurement in the actual ambient conditions (27-30.09.2024).

Figure 5(a)-(d) represents the temperature changes at the measurement points for the test cabins where REF (reference) and SSPCM were included (OUT2H, IN2H and FULL4H) in the outdoor experiments dated 27-30.09.2024. These recorded temperature data are important in evaluating the energy storage performance of the building material of the proposed composite SSPCM. The ambient temperature expressed by TC21 varies between 14 °C and 36.59 °C, including the melting and solidification temperatures of SSPCM, when all days are considered. The ambient temperature, which interacts with direct solar radiation, gradually increases with sunrise. The ambient temperature, which is 14 °C-15 °C around 06:00, reaches its maximum value of 36.59 °C at noon (~12:00). Incoming solar radiation is at its highest level at this time. With the decrease in solar radiation, the ambient temperature gradually decreases until sunset. The ambient temperature, which falls below 25 °C until 18:00, remains between 15 °C and 20 °C at midnight. For all the working days when the experimental analyses were carried out, the changes observed in the cabin temperatures were slower than the outside temperature due to the materials used for thermal insulation in the test rooms. The measured values for the cabin temperatures were quite high compared to the ambient temperature. The temperatures of the reference room and the test rooms with SSPCM showed a similar trend throughout the experiment. For the temperatures where similar values were obtained, significant differences were mostly seen during the period between noon and sunset. When the temperature changes that occurred due to weather conditions on consecutive days were taken into account, the outer surface responded quickly to the weather conditions, while on the contrary, the temperature changes in the room center occurred more slowly. While the amount of radiation increases with sunrise, the indoor and sample temperatures started to increase and higher values were reached compared to the ambient temperature due to this increase. The effect of SSPCM is more noticeable at high temperatures. The room centers of the OUT2H, IN2H and FULL4H test cabins are significantly colder during the day compared to REF. This plays an important role in reducing the cooling load of the buildings. This is related to the solar energy storage feature of the MP in the SSPCM structure.

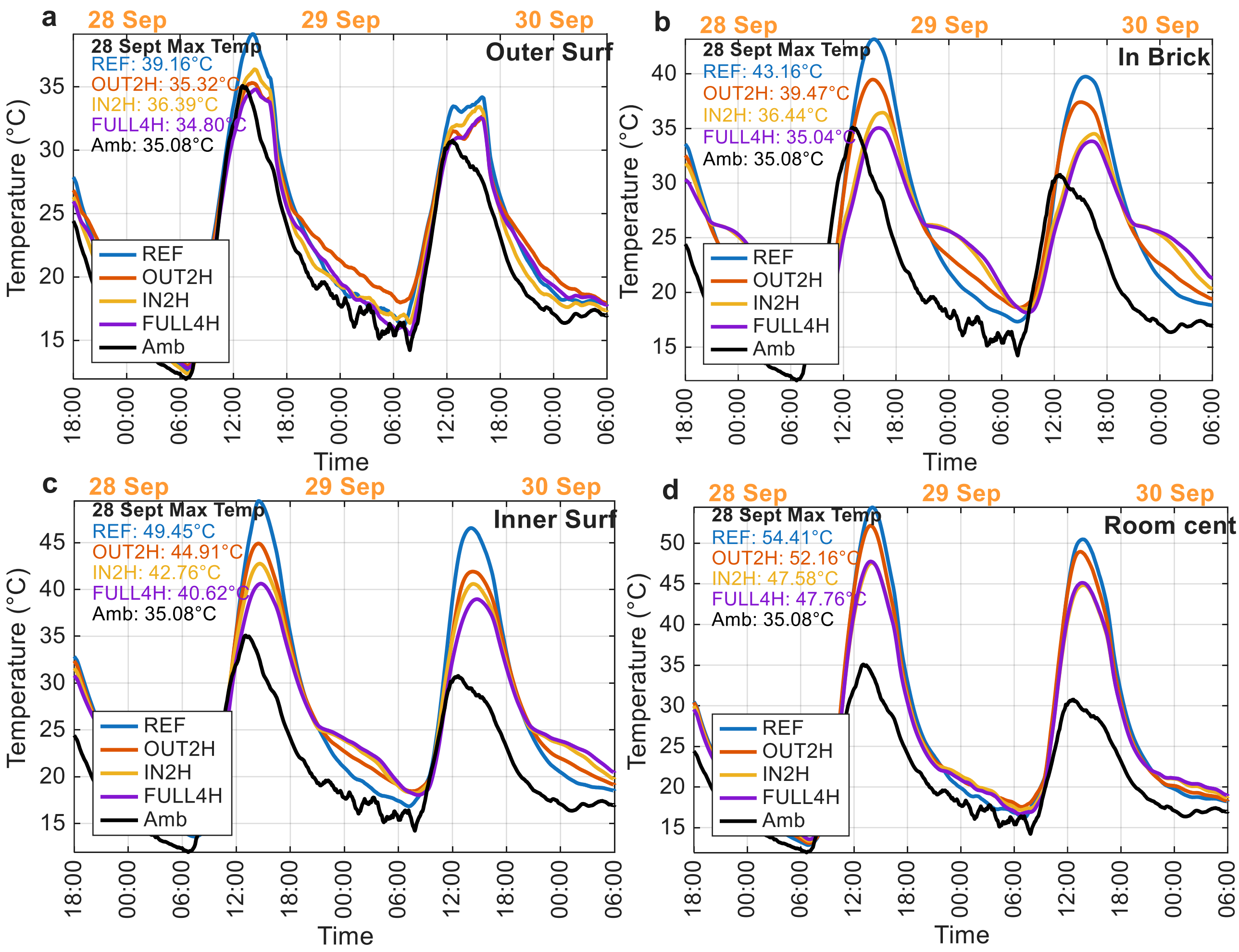

Figure 5. Outer surface (a), in brick (b), inner surface (c), and room center (d) temperatures in the experimental rooms including Reference, OUT2H, IN2H, FULL4H cases from 18:00, 27 Sept. to 06:00, 30 Sept. 2024.

The advantages of SSPCM test cabin temperatures for thermal comfort are more clearly seen for hours of intense solar radiation under clear sky conditions. In cloudy weather, a decrease in the energy flow occurs due to the blocking of direct solar radiation and the temperatures tend to be closer to each other. For the test samples with SSPCM, the most significant differences between the measurement points compared to REF are generally observed in the brick. The maximum temperature inside the brick for REF was measured as 43.23 °C, while it was determined as 35.10 °C in the FULL4H brick. Compared to OUT2H where the outer hollows were filled, filling the inner hollows with PCM provides a decrease in the brick in peak temperature from 39.56 °C to 36.47 °C. The maximum temperature was measured as 54.59 °C at the room center of REF during the period when the heat load was high. In contrast, the temperatures of the room centers of OUT2H, IN2H and FULL4H were 52.32 °C, 47.73 °C and 47.89 °C, respectively. The inner surface temperatures were higher than the outer surface temperatures, and maximum temperatures of 40.07 °C and 49.57 °C were observed on the outer and inner surfaces. During the peak hours, the outer surfaces of the OUT2H and IN2H test cabins had maximum temperatures of 35.91 °C and 37.17 °C, respectively, at the hottest hour of the day. In FULL4H, maximum temperatures of 35.47 °C and 40.72 °C were recorded on the outer and inner surfaces, respectively. Indoor temperatures have begun to drop due to decreasing solar altitude and incoming radiation. Until midnight, the temperatures of the measurement points, where a gradual decrease was observed, remained between 20-25 °C throughout the night. The results show that the proposed SSPCM integrated building material provides a significant improvement in preventing overheating and maintaining indoor thermal comfort conditions.

In Figure 6(a)-(d), the temperature differences (ΔT) between the test cabins containing the reference and SSPCM samples are given for a clearer understanding of the effect of the proposed SSPCM. In the difference calculations made for the measurement points, the reference cabin temperatures were subtracted from the test cabin temperatures with SSPCM. Positive values observed for ΔT indicate that the test cabin temperatures with SSPCM were higher, while negative values indicate that the reference was higher. The advantages of SSPCM were clearly observed in the comparative analysis. As the solar radiation reached the windows of the rooms after sunrise, the proposed SSPCM temperature increased up to the phase change temperature. As the SSPCM started to store energy, the temperature increase was slower in the SSPCM bricks compared to the reference, and the differences between the test cabins gradually increased until noon.

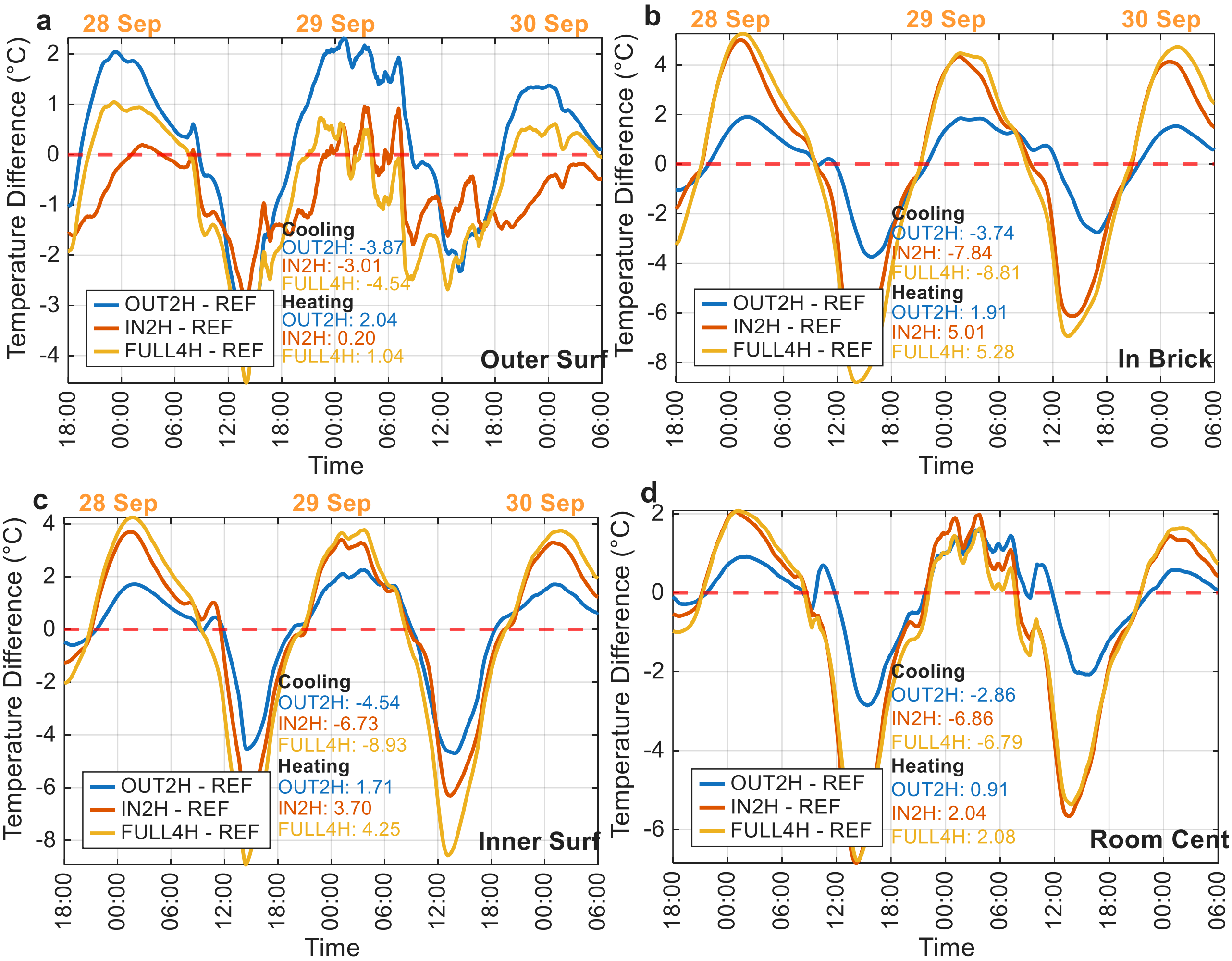

Figure 6. Temperature difference between of outer surfaces (a), in bricks (b), inner surfaces (c), and room centers (d) temperatures of Reference room and OUT2H, IN2H, FULL4H cases from 18:00, 27 Sept. to 06:00, 30 Sept. 2024.

The effect of SSPCM on thermal comfort is more clearly seen during this period. A low indoor temperature plays a very important role in reducing the cooling load in buildings. While the REF room exhibits warmer indoor temperatures during the hours when the cooling load is high, the opposite is achieved with the recommended SSPCM composite during the night hours when the ambient temperature drops as the incoming radiation begins to decrease. High surface temperatures are preferred to minimize heat loss from human skin and increase thermal comfort in cold weather conditions. Although the insulation applied to the cabin surfaces provides an advantage in delaying the decrease in indoor temperatures, it has been determined that the test rooms with SSPCM offer more suitable temperatures in terms of the indoor environment. In general, the temperature change on the outer surface was less than the other positions. For the periods when heating and cooling loads were high, significant temperature changes of 5.63 °C and 2.14 °C were obtained on the outer surface. While the greatest contribution in cooling was provided by FULL4H, OUT2H came to the forefront for heating. In the case of the inside of the brick, where the effect of PCM on the heating load was observed most clearly, FULL4H was 5.30 °C warmer than the reference. The minimum contribution for both cooling and heating was seen in OUT2H with 3.79 °C and 1.93 °C, respectively. When the period when heat loads were high was taken into consideration, the inner surface temperature of FULL4H was significantly lower (9.12 °C) among the other samples. For the inner surface, IN2H had a greater effect on the heating and cooling performance than OUT2H. In the case of room center, maximum temperature differences of 7.05 °C and 2.16 °C were obtained with IN2H and FULL4H during day and night periods, respectively. In the findings, the advantage of SSPCM becomes more noticeable in reducing the cooling load. Considering all the cases, although the amount of PCM contributes positively to the performance improvement, this contribution varies depending on the PCM location. The proposed EV-MP composite provides a location-dependent increase of 0.99 °C (min.)-2.16 °C (max.) in room core temperature during night and a decrease of 3.15 °C (min.)-7.05 °C (max.) during day, highlighting its significant potential in controlling thermal comfort for building applications.

4. Conclusions

In this study, the effects of using the developed SSPCM composite in different ratios in the bricks forming the external walls of buildings in terms of thermal performance were presented. The summary of the experimental analysis findings is as follows:

- In terms of thermal comfort; the integration of SSPCM into bricks contributes to the control of indoor temperatures and the reduction of heating-cooling loads by optimizing the heat transfer from the wall surface to the room center.
- The effectiveness of SSPCM in reducing the cooling load for the hours when solar radiation is intense can be seen more clearly. The maximum difference of 9.12 °C was obtained with FULL4H on the indoor surface.
- Positioning SSPCM in the inner hollows plays a more effective role in reducing the energy consumption for heating-cooling compared to positioning in the outer hollows. Increasing the filling ratio of SSPCM has a significant effect on the improvement of thermal performance.
- The observed improvement for the outer surface was generally less than the other locations. In the periods when the heating and cooling loads were high, the temperature changes of 5.63 °C (FULL4H) and 2.14 °C (OUT2H) were detected on the outer surface, respectively.
- Considering the period when the heat loads were high, the inner surface temperature of FULL4H was significantly lower (9.12 °C) among the other samples. In the night period, the advantage provided reached 4.27 °C.
- In the inside of the brick, where the most significant difference in terms of heating load was seen, FULL4H was 5.30 °C warmer than the reference. Considering the inner part of the brick, the minimum temperature difference observed for both cooling and heating was 3.79 °C and 1.93 °C in OUT2H.
- In the day and night periods, SSPCM provided an advantage of 7.05 °C and 2.16 °C in the room center, respectively.

The findings clearly show the effect of SSPCM on reducing the cooling load in terms of improving thermal comfort. Although the amount of PCM contributes positively to the performance improvement for all cases, this contribution varies depending on the location. The proposed SSPCM composite is a material with high potential to be used in building walls in terms of energy saving and reducing carbon emissions by providing cooler surface-indoor temperature and warmer surface-indoor temperature at noon and night hours, respectively.

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Author contribution

All authors contributed substantially and equally to all stages of the manuscript's conception, development, and finalization.

Declaration of ethical code

The author(s) of this article declare that the materials and methods used in this study do not require ethics committee approval and/or legal-special permission.

Conflicts of interest

The author(s) declare that there is no conflict of interest.

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